UNIVERSITY OF ILLINOIS BULLETIN
Vol. IV MAY 15, 1907 No. 19

Entered Feb. 14, 1902, at Urbana, Ill., as second-class matter under act of Congress of July 16, 1894

The University Studies

Vol. II MAY, 1907 No. 4

A PRECISE METHOD OF ROASTING BEEF

By

ELIZABETH C. SPRAGUE,
Research Assistant, Nutrition Investigations

and

H. S. GRINDLEY, Sc.D.,
Professor of General Chemistry

PRICE $1.00

University Press
Urbana

University of Illinois

The University Studies

Vol. II. No. 4. MAY, 1907

A PRECISE METHOD OF ROASTING BEEF

By

ELIZABETH C. SPRAGUE,
Research Assistant, Nutrition Investigations

and

H. S. GRINDLEY, Sc D.,
Professor of General Chemistry

PRICE $1.00

University Press
Urbana

A PRECISE METHOD OF ROASTING BEEF

During the course of extended investigations upon the chemistry of the cooking of meats, which are being made in the Department of Chemistry of this University, it was found necessary to devote some time to the consideration of the practical question of the methods of cooking. In preparation for a series of experiments to determine the losses and the chemical changes which occur when meat is roasted, a few preliminary experiments were made to establish certain standards for the cooked meat and to determine the conditions necessary to attain these.

The different degrees, designated as rare or underdone, medium rare, and well done, to which meat may be roasted are at present largely matters of individual opinion. What may seem rare to one person, is medium rare to another, while it is not at all uncommon to have meat that is actually raw offered as rare. The usual household method of attaining these different degrees by allowing for the time of cooking, a definite number of minutes for each pound of meat contained in the roast, while reliable to some extent, is not sufficiently accurate for careful investigations. Under such conditions, considerable variations may occur in the degree of cooking, and it has already been shown[1] that the percentages of the original constituents of the raw meat which are removed by cooking depend on this factor.

DEGREES OF ROASTING

To almost every one, the sight of a well browned roast or steak, somewhat glossy from the mixture of melted fat and semi-carbonized substances with which its surface is bathed, and well puffed up by the contraction of the outer fibres is much more appetizing than one which is a dull gray in color, sodden and shrunken in appearance. As regards the interior of the meat, however, there is a greater diversity of taste, ranging

[1] U. S. Dept. of Agr. Office of Experiment Stations. Bul. 141, p. 93.

from that which prefers that the meat shall have been heated only enough to change slightly the color of the interior to that which insists upon the disappearance of every trace of pink color. There are at least three grades of roasted meat, i. e., rare or underdone, medium rare, and well done.

Rare or Underdone Meat. A cross-section of a rare roast shows the three distinct changes which occur in roasting. One of these changes is seen in the center where the dull, bluish red characteristic of the raw meat has changed into the bright rose red of rare meat. This shades into a lighter pink toward the outer portions and changes into a dark gray in the layer immediately underlying the outer browned crust. The ideal standard for rare meat requires that the larger portion of the roast shall have been heated only enough to effect this first change to rose red, so that the outer brown crust and the intermediate gray layer shall be as thin as possible. Under these conditions there should be a liberal amount of bright red juice.

Well-done Meat. If the cooking is continued for a sufficient length of time, instead of being distended the meat shrinks noticeably, the whole interior is found to have become brownish-gray in color and the juice is scanty and either colorless or slightly yellow. Meat cooked to this degree is said to be well-done.

Medium Rare Meat. A condition between these two extremes is indicated by the term medium rare. In this case, sufficient heat has been applied to change the color of the center to a light pink. The gray layer underlying the crust has therefore extended considerably toward the center and the free juice is smaller in quantity and lighter in color than in the rare meat.

TEMPERATURE OF THE INTERIOR

The degrees of cooking indicated above are dependent upon the temperature which is reached in the interior of the meat during cooking. A number of investigators have observed the degree of heat which penetrated to the interior of various cooked

meats. This varied from 28.75° C. in quickly roasted sausage to 98° C. in roasted veal. Wolffhügel and Hüppe[1] demonstrated that the temperature in the interior of large pieces of meat never rises to 100° C., even after several hours boiling or roasting. Such researches as the above, which have been made in considerable number had for their object the determination of the extent of sterilization which was effected by the process of cooking and are not pertinent to the present study. Sir Henry Thompson[2] also ascertained the maximum temperature attained in meats cooked by various methods and found that however thoroughly the meat had been cooked the mercury never rose above 185° or 187° F. (85.5° – 86° C.). It was generally a little below this limit.

Strohmer[3] says of the juice pressed from cooked meat that "if it is a clear red, the temperature was probably between 50° C. and 60° C., but not exceeding 65° C. Between 70° C. and 72° C. the color of the juice changes to brownish red, and between 75° C. and 80° C. to yellow." Liebig[4] is quoted as authority for the following: "When a watery infusion of meat is heated to 133° F. (56° C.), flakes of whitish matter separate. These flakes are albumin. When the temperature is raised to 158° F. (70° C.) the coloring matter of the blood coagulates and the liquid which was originally tinged red by this substance is left clear and almost colorless..... Beef or mutton cannot be said to be sufficiently roasted until it has acquired throughout the whole mass a temperature of 158° F., but poultry may be well cooked when the inner parts have attained a temperature of from 130° to 140° F. (55° to 60° C.). This depends upon the greater amount of blood which beef and mutton contain." Yeo[5] on the other hand makes the following statement. "If the temperature of the interior of the joint does not rise above 130° F. (55° C.) it remains reddish, blood tinged, and

[1] Ostertag-Wilcox's Handbook of Meat Inspection, p. 843.
[2] Food and Feeding, p. 96.
[3] Mitchell's Flesh Foods, p. 214.
[4] Mrs. Beeton's Household Management, p. 267 to p. 313.
[5] Food in Health and Diseases, p. 159.

'under-done.' For beef, mutton, and game this temperature is sufficient and gives the tenderest meat and the best flavored, but for veal and poultry a higher temperature, 157° F. to 160° F. is needed."

J. H. Milroy[1] found that at 50° C. from 45.95 per cent to 55.10 per cent of the albuminous matter of fresh beef was coagulated; at 60° C. from 64.37 per cent to 74.47 per cent; at 70° C. from 90.66 per cent. to 91.01 per cent; and at 80° C. from 99.11 per cent to 100 per cent.

From this it will be seen that one-half of these substances is coagulable below 50° C. (122° F.) and practically all of them between 70° C. and 80° C. (154° to 176° F.). At the latter temperature, oxyhaemoglobin undergoes a decomposition[2] which probably marks the disappearance of the last trace of red in the juice.

These observations suggested a method of determining the degree of cooking which had been reached in a roast. So many factors affect the results obtained by this mode of cooking, e. g., temperature of oven, size and shape of roast, kind and quality of meat, and so forth, that no satisfactory rule has as yet been formulated for this process. Knowing the temperature of the oven, one may be guided somewhat by the time of cooking, but oven heat is variable and as yet no oven thermometer suitable for common use has been devised. Moreover under apparently identical conditions of cooking, different results have been obtained.

Even after long experience, little reliable information can be gained from the appearance of the outside of the meat. Though a roast may, when judged by external appearances seem to be sufficiently cooked, it may prove very much underdone when cut. The roasting of beef seems to the average housekeeper to contain many elements of chance, and her anxiety is seldom relieved until the carver reveals the condition of of the interior of the roast. This anxiety has weighed so heav-

[1] Archiv. f. Hyg., 1895, XXV, p. 154.

[2] Mitchell's Flesh Foods, p. 37.

ily upon the minds of some cooks that they have been heard to declare that they would rather prepare all the rest of the dinner than to roast the meat.

Therefore, a method of knowing the condition of the interior of the meat, regardless of its external appearance, might prove of considerable help, especially to the inexperienced housekeeper. It seemed that such a method might be found by applying the foregoing principles. Since the degree of cooking depends upon the extent of the coagulation of the soluble proteids of the meat, it should be possible to control the cooking by observing the temperature of its interior during the process. The range of the inner temperature of the cooked meats seemed to be from 50° C. for rare meat, at which about half of the soluble proteids become insoluble, to 80° C. for well done meats when practically all of these constituents are coagulated. In order to test this theory a few experiments were performed by the writers in this laboratory.

PRELIMINARY COOKING EXPERIMENTS

Four single, short rib roasts of beef containing the bone were used in these experiments. These were as nearly as possible of the same size, degree of fatness, and so forth. It was the purpose of these experiments to compare the physical condition of the meat cooked under the same conditions, until the temperature in the center of the roasts reached respectively 50° C., 60° C., 70° C., and 80° C.

Each roast was placed upright upon the rack of an open dripping pan, the fat side being uppermost. An incision was made to its center with a sharp, narrow-bladed knife, and a short chemical thermometer, registering 100° C., inserted in such a way that the bulb was as nearly as possible in the center of the large muscle of the roast. It was then placed in an oven at a temperature of 249° C. (450° F.). This temperature was maintained for fifteen minutes to sear the meat thoroughly and then reduced to 193°C. (380° F.) for the remainder of the time of cooking. The meat was removed from the oven when

the thermometer in the center of the roast registered the desired degree, allowed to stand at the room temperature for from thirty to forty-five minutes, then placed in a tightly covered glass sample jar over night. In the morning it was cut through the center, the physical condition noted, and a water color painting made.

RISE OF TEMPERATURE AFTER REMOVAL FROM OVEN

The first roast was removed from the oven when the thermometer in the meat registered 60° C. (140° F.). After removal from the oven the temperature continued to increase slowly for ten minutes, at the end of which time it registered 64.5° C. (148° F.). A similar increase in temperature occurred in each case, except in that of the roast cooked well-done, when the temperature remained stationary after the meat was removed from the oven.

On account of this rise it was found difficult to carry the temperature to exactly the degree required, but the final figures do not differ greatly from the desired degrees. The temperatures registered in the meat when removed from the oven and the subsequent rise in temperature are tabulated with other data below in Table I.

TABLE I.—Time of Cooking and Temperature of Interior of Single, Short-rib Roasts.

No. of roast.	Weight of roast.		Time of cooking.			Innerte mperature.						Condition of cooked meat.
			Total.		Rate per pound	When removed from oven.		Maxim'm reached after removal.		No. degrees rise after removal.		
	Lbs.	Ozs.	Hrs.	Mins.	Mins.	°C.	°F.	°C.	°F.	°C.	°F.	
1	4	4.25	1	10	16.3	46.5	116	53.5	128	7.5	12	Very rare.
2	4	2.75	1	20	19.2	60.0	140	64.5	148	4.5	8	Medium, verging on rare.
3	3	0.25	1	25	28.2	66.5	152	69.0	156	2.5	4	Medium, verging on well-done.
4	3	5.00	1	40	30.4	79.0	174	79.0	174	....	....	Well-done.

It will be observed that the rise of temperature was greatest when the temperature of the meat as taken from the oven was lowest, and that this rise decreased as the temperature of the interior increased until at 79° C. (174° F.) there was no rise. The rise of temperature after removing from the oven therefore would seem to depend partly upon the difference in temperature between the outside and the inside of the meat, i. e., the greater the difference in temperature, the greater will be the rise.

In the case of one roast which is not included in the table, an attempt was made to over-cook the meat very much by raising the inner temperature to 100° C. (212° F.). Although the roast was thinner than usual, at the end of one and one-half hours the inner temperature was only 82° C. (180° F.) and at the end of two hours, 95.5° C. (204° F.), at which time the outside of the meat was very much burned. It is evidently difficult on account of its poor conducting qualities to raise the temperature of a roast very much above the highest coagulating point of the proteids present. In one case the thermometer was left in the meat for thirty minutes after the maximum temperature, 66.5° C. (156° F.), had been reached and at the end of that time it had fallen to only 60° C. (140° F.). The poor conducting power of meat has been discussed by Ostertag.[1]

RISE OF TEMPERATURE OF THE INTERIOR OF MEAT DURING COOKING

Although in the process of roasting, the meat is submitted to a temperature far in excess of that suitable for the cooking of proteid, it is evident that only a very thin outside layer of the meat is affected by this temperature. The temperature of the interior rises very slowly and follows the same rule as does the rise in temperature after removing from the oven. That is, the greater the difference between the temperature of the outside and the inside of the meat, the greater is the rise of temperature. In the case of three of the roasts, the rise of tempera-

[1] Handbook of Meat Inspection p. 843.

ture during cooking was noted at stated intervals. These observations are tabulated in Table II.

TABLE II.—Rise of Temperature of Meat during Cooking.

	Time in the oven.	Inner temperature of meat.		Rise of temperature.		Rise of temperature per min.	
	Mins.	° C.	° F.	° C.	° F.	° C.	° F.
Roast No. 3[1]	30	24.4	76	.....	.....	.....	.....
Roast No. 3	45	40.0	104	15.6	28	1.04	1.87
Roast No. 3	60	52.2	126	12.2	22	0.81	1.47
Roast No. 3	75	61.1	142	8.9	16	0.59	1.07
Roast No. 3	85	66.5	152	5.4	10	0.54	1.00
Roast No. 4	30	27.8	82	.....	.....	.....	.....
Roast No. 4	45	44.4	112	16.6	30	1.11	2.00
Roast No. 4	60	57.8	136	13.4	24	0.89	1.60
Roast No. 4	75	68.9	156	11.1	20	0.74	1.33
Roast No. 4	90	75.5	168	6.6	12	0.44	0.80
Roast No. 4	100	79.9	174	3.5	6	0.35	0.40
Roast No. 1[2]	40	30.0	86	.....	.....	.....	.....
Roast No. 1	55	39.4	103	9.4	17	0.63	1.13
Roast No. 1	70	46.7	116	7.3	13	0.48	0.87

[1] Less fat than No. 4.

[2] About one inch wider across the back than Nos. 3 and 4.

It will be observed that the rise of temperature is more rapid during the earlier part of the cooking and decreases as the time of cooking increases. For example, in roast No. 3 in the period between thirty and forty-five minutes after going into the oven, the temperature rose at the rate of 1.04° C. per minute. In the last period of ten minutes, beginning seventy-five minutes after going into the oven, the rise in temperature was only 0.54° C. per minute. Or otherwise stated the rise of temperature was most rapid between 25° C. and 45° C. Between 45° C. and 70° C. the rate of rise decreased and between 70° C. and 80° C. it was still more gradual. In two cases (Nos. 3 and 4) the rate of rise is very similar, except during the last period of ten minutes. The comparative rise of temperature in these cases is illustrated in Diagrams I and II. The difference in the rise of temperature in Nos. 3 and 4 may have been

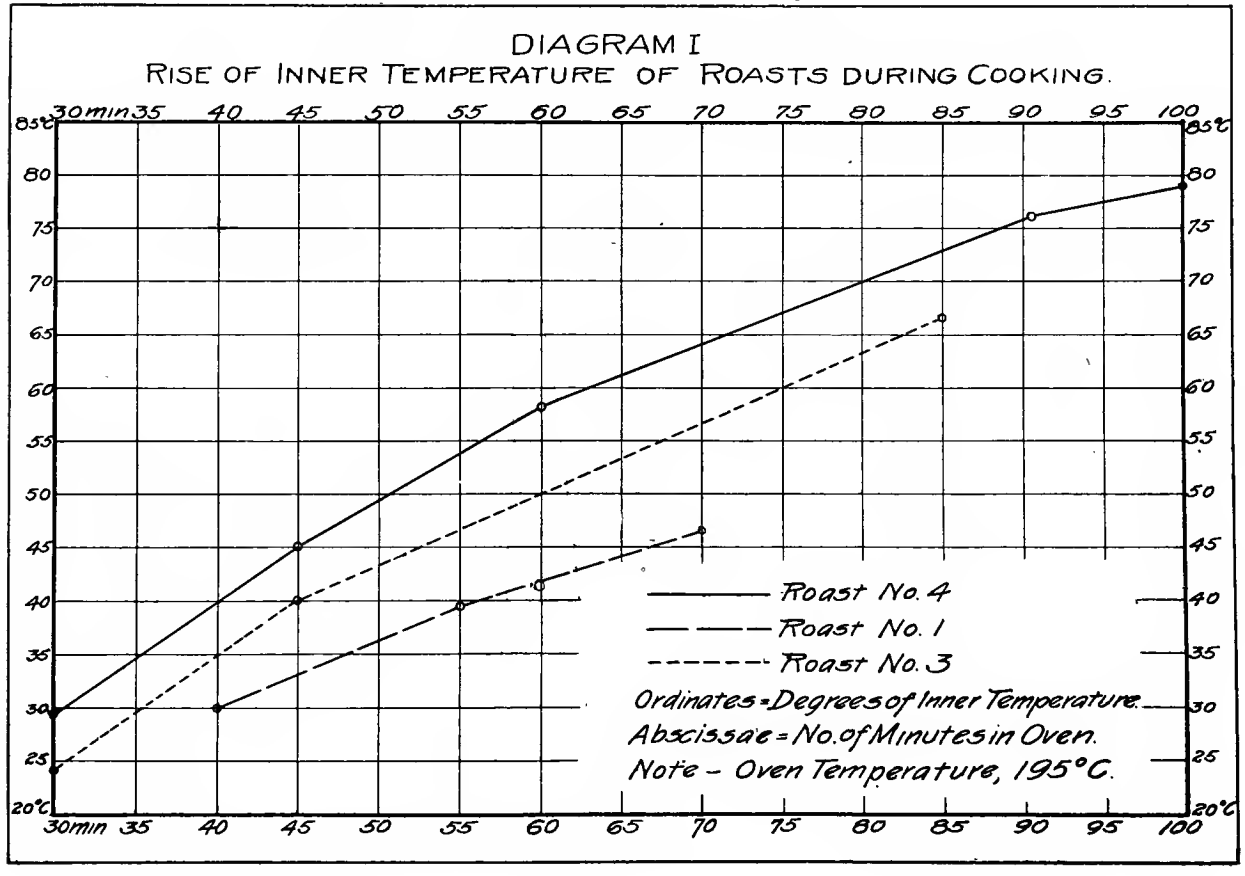


DIAGRAM I
RISE OF INNER TEMPERATURE OF ROASTS DURING COOKING.
30min 35 40 45 50 55 60 65 70 75 80 85 90 95 100
85°C
80
75
70
65
60
55
50
45
40
35
30
25
20°C
Roast No. 4
Roast No. 1
Roast No. 3
Ordinates = Degrees of Inner Temperature.
Abscissae = No. of Minutes in Oven.
Note – Oven Temperature, 195°C.

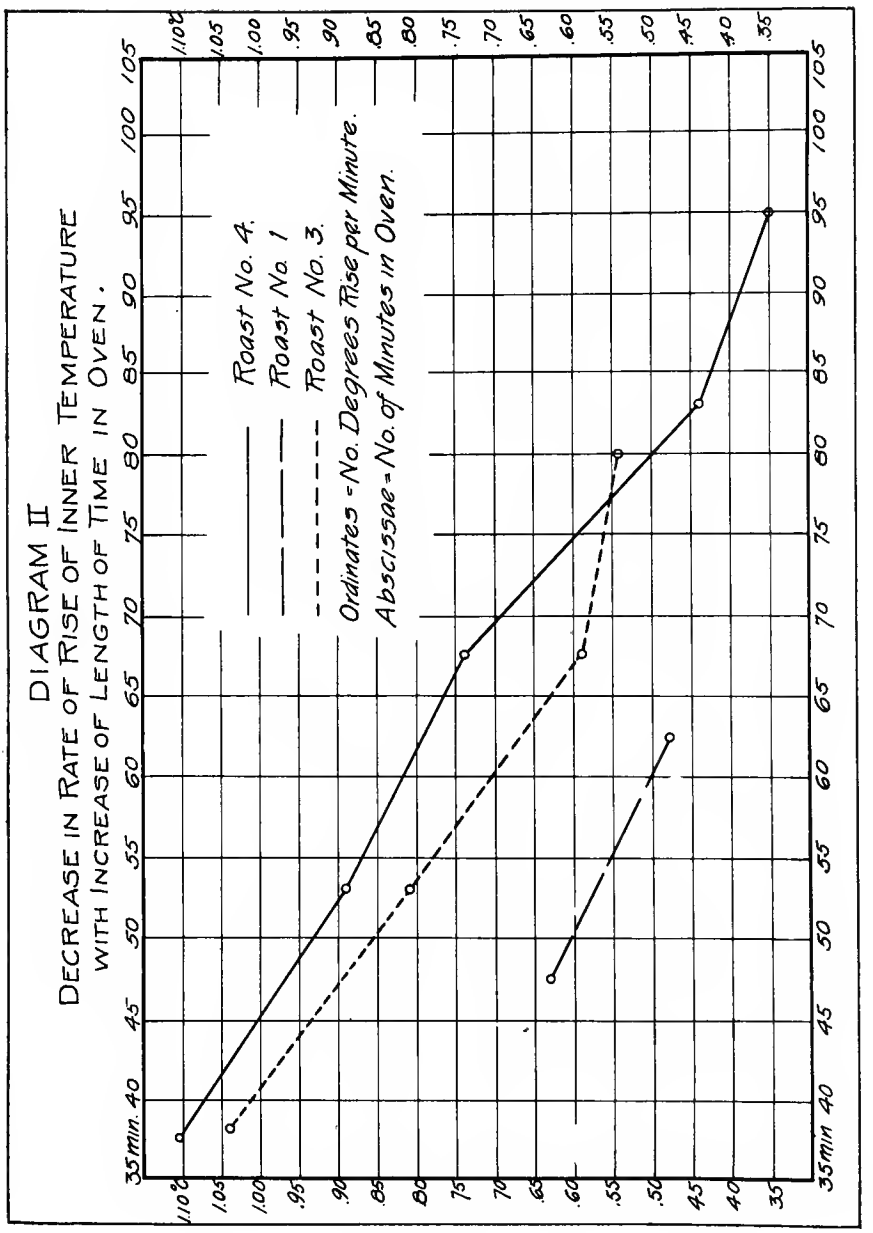


DIAGRAM II
DECREASE IN RATE OF RISE OF INNER TEMPERATURE
WITH INCREASE OF LENGTH OF TIME IN OVEN.
Roast No. 4.
Roast No. 1
Roast No. 3.
Ordinates = No. Degrees Rise per Minute.
Abscisae = No. of Minutes in Oven.
35 min. 40 45 50 55 60 65 70 75 80 85 90 95 100 105
1.10 1.05 1.00 .95 .90 .85 .80 .75 .70 .65 .60 .55 .50 .45 .40 .35

due to a difference in the temperature of the meat before going into the oven, which was not observed. It may possibly have been due also to a difference in the amount of fat. There was less external fat in No. 3 than in No. 4. Apparently fat tissue conducts heat more rapidly than does the muscular tissue. This statement has been made also by Glage.[1]

Drucker[2] also mentions that uniformly lean meat is the most difficult to cook through. On the other hand Hoffman[3] states that "the fat pieces of flesh are the more difficult to sterilize, the fat preventing a thorough penetration of the heat." This is in accord with the conclusions of various physiologists that fat is a poorer conductor of heat than is muscle fiber. The atter however are based upon the conductivity of fresh muscle fiber and may not apply under the conditions attending the application of heat during roasting. Since the proteids of the outer surface of the meat are coagulated immediately upon going into the oven, the comparison as regards conductivity must be made between the fat and the coagulated muscle fiber. Hoffman[3] also mentions that the coagulation of the proteids makes the penetration of the heat more difficult. Moreover the fat is capable of acquiring a higher temperature than is the lean which contains so large a proportion of water.

It will be noticed in the illustrations that the small outer muscles, which are surrounded with fat, are cooked "well-done" even in the case of the very rare roast (See Plate I), showing that to a depth of one or two inches from the back a temperature of more than 69° C. (156° F.) had been reached since at the latter temperature a little color should remain. A cut from the outside of the large center muscle of Nos. 1 and 2 showed that from this direction, this degree of heat had penetrated not more than one-quarter of an inch, since that was the depth of the "well-done" crust. It must be remembered,

---

[1] Ostertag-Wilcox, Handbook of Meat Inspection, p. 843.
[2] Zeit. für Fleisch- und Milch Hyg. v. 2, p. 21-24.
[3] Zeit. für Fleisch- und Milch Hyg. v. 13, p. 207.

however, that the small muscle at the back is affected by heat conducted from two directions while the large center muscle is subjected to heat from one side only.

The difference in the rise of temperature between Nos. 3 and 4 is much less than that between No. 1 and either of the former. At the end of 75 minutes after being placed in the oven, No. 3 registered 61.1° C. (142° F.), while at the end of the same length of time, No. 4 registered 68.9° C. (156° F.), a difference of 7.8° C. At the end of 70 minutes, No. 1 registered only 46.7° C (116° F.), a difference of 14.4° C. as compared with No. 3, and of 22.2° C. as compared with No. 4. This was probably due to the fact that No. 1 was almost one inch wider across the back than the other samples. It seems probable that time and temperature being constant, the degree of cooking of a rib roast will be dependent upon (1) thickness from back to rib bone, (2) width across the back, and (3) degree of fatness.

Certain characteristics of the different degrees of cooking are well shown by the illustration. One extreme is shown by the very full, plump appearance of the very rare roast, (See Plate I) indicating a minimum loss of both water and fat. This roast in which the maximum temperature reached at the center was 53.5° C. (128° F.) was very rare throughout, apparently as much so as the most extreme taste would desire. By some, the roast illustrated in Plate II, in which the temperature at the center was 64.5° C. (148° F) might be called rare although it seems more properly to mark the beginning of the medium rare stage. This gives a range of 11° C. in which the meat might be cooked rare.

The other extreme of medium cooked meat, having only a slight trace of pink remaining, is illustrated in Plate III. In this case the inner temperature reached 69° C. (156° F.). This gives a range for medium cooked meat of only about 5° C. In Plate IV is seen an example of well-done meat in which all pink color is destroyed. The inner temperature of the center of this roast reached 78° C. (174° F.), giving a range of 10° C. for the well done stage. In other words if the inner temperature

of a roast is between 55° C. and 65° C. the meat will be rare; if it is between 65° C., and 70° C., it will be medium rare; and if between 70° and 80° C., it will be well done.

The increase in the loss of water and fat as the degree of cooking increases, is shown by the drawing away of the flank muscles from the end of the bone. The outer layer of fatty tissue is gradually emptied of its contents, until in the very well-done roast it is principally a crisp layer of connective tissue, holding a comparatively small percentage of fat.

THE INFLUENCE OF OVEN TEMPERATURE IN ROASTING

Since the determination of the temperature reached in the center of the meat seemed to offer a reasonable basis for determining and regulating the degree of cooking, a series of experiments was made to study the influence of the oven temperature in cooking meats to the three different degrees. The third and fourth standing rib cuts from animals about three years old were selected for these experiments. The roasts were as uniform in size and character as could be obtained from the local market. Although unusual care was taken in this respect there was necessarily more or less variation in the character of the different samples. The meat was freed from bone, tightly rolled and secured with steel skewers. An incision was made to the center of the meat with a sharp, narrow-bladed knife and a short chemical thermometer inserted in such a way that the bulb of the thermometer reached the center of the large muscle of the roast.

Each roast was placed on the rack of an open dripping pan, the fat side being uppermost, so that the two cut surfaces were equally exposed to the oven heat. In every case the meat was first placed in the oven at a temperature of 250° C. and this temperature maintained for fifteen minutes to sear the surface of the meat. The temperature was then reduced to the degree desired for the remainder of the cooking. This, for the high oven temperature, was 195° C.; for the medium, 175° C.; and

for the low temperature, 100° C. For the longer part of the process, 195° C. seemed as high a temperature as could be used without causing excessive browning of the surface. The medium temperature was selected as representing a condition of the oven, familiar to most housekeepers for bread-baking purposes.

With the low temperature, the objects were to use as nearly as possible the maximum temperature (83° C.) which is theoretically suitable for proteid substances, and to produce, at the same time, the searing and browning of the outer surface, which is essential in well roasted meat. It having been demonstrated that when cooked at 83° C. the meat came from the oven gray and unattractive looking,[1] it was decided to raise the temperature of the oven to 100° C. in these experiments.

At the two higher temperatures the whole process was carried on in the oven of a gas range. For cooking at the low temperature the same oven was used for the preliminary fifteen minutes searing, after which the meat was transferred to the Aladdin[2] oven for the remainder of the cooking. In this oven it is possible to maintain an even temperature, and there is practically no oven ventilation.

In order that the maximum inner temperature of the center after removal from the oven should approximate 55° C. for the rare, 65° C. for the medium rare, and 75° C. for the well-done meat it was found necessary to remove the roasts at 43° C., 55° C., and 70°C., when the temperature of cooking was either 195° C. or 175° C. When the temperature of cooking was 100° C. it was necessary, for reasons to be hereafter stated, to allow the inner temperature to reach higher degrees in each case before removal from the oven.

In the first series of experiments, duplicate cuts from the right and left side of the same animal were roasted side by side under exactly the same conditions in order to test the method of cooking. After cooling over night the roasts were cut through the center and their physical appearance compared.

[1] Univ. of Ill. Agr. Exp. Sta. Cir. 71, p. 24.

[2] Atkinson's Science of Nutrition.

Afterwards one roast was taken for analysis and the other tested for flavor, toughness, and so forth. The results of this series are tabulated below.

TABLE III. Time of Cooking and Inner Temperature of Duplicate Roasts.

Cooking Experiment No.	Laboratory No.	Weight of roast.		Temperature first 15 minutes.	Temperature remainder of time.	Total time of cooking.		Total time per pound.	Inner temperature when removed.	Maximum inner temperature.
		Lbs.	Ozs.	°C.	°C.	Hrs.	Mins.	Mins.	°C.	°C.
169	1833	5	5.5	250	195	1	40	18.7	43	57
Duplicate...	1834	4	11.0	250	195	1	35	20.2	43	58
170	1836	4	7.75	250	195	1	35	21.1	43	53
Duplicate...	1837	4	6.5	250	195	1	30	20.5	43	56.5
Average..	(4)....	4	11.64	.....	.....	1	35	20.1	.....	56.1
171	1838	3	5.0	250	195	1	35	28.6	55	62.5
Duplicate...	1839	3	7.0	250	195	1	40	29.0	55	64.0
172	1840	5	7.0	250	195	2	30	27.5	55	61.5
Duplicate...	1841	5	6.5	250	195	2	15	25.0	55	62.5
173	1842	3	15.5	250	195	1	50	27.7	55	61.5
Duplicate...	1843	3	13.75	250	195	1	55	29.8	55	62.5
Average..	(6)....	4	3.79	.....	.....	1	58	27.9	.....	62.6
174	1844	5	2.75	250	195	3	00	34.7	70	74
Duplicate...	1845	5	1.0	250	195	3	00	35.5	70	74
175	1846	4	10.5	250	195	2	45	35.4	70	73
Duplicate...	1847	4	11.25	250	195	2	30	31.8	70	73
Average..	(4)....	4	14.37	.....	.....	2	49	34.4	.....	73.5

With the exception of the two roasts in Experiment No. 169, the duplicates compared very closely in weight. In Cooking Experiments Nos. 169, 170, 171, and 173 there was a difference of 5 minutes in the total time of cooking of the two roasts, and in Nos. 172 and 175 there was a difference of 15 minutes. The difference in the time of cooking per pound of the duplicate

roasts, ranges from 0.4 in Cooking Experiment No. 171, to 3.6 minutes in Cooking Experiment No. 175. In Experiments No. 169 and 175 where the difference in the time of cooking was greatest, there was a noticeable difference in the degree of cooking of the two duplicates, those which were cooked for the shorter time per pound being less thoroughly cooked than their duplicates. This in both cases was due to a slight difference in the position of the thermometers in the roasts. In all other cases the duplicate roasts compared very closely in the degree of cooking, as judged by physical appearance.

TIME PER POUND IN RELATION TO DEGREE OF COOKING

In the four roasts which were cooked to 43° C. (rare or underdone) at 195° C., the time per pound ranged from 18.7 minutes to 21.1 minutes, averaging 20.1 minutes. In the six roasts which were cooked to 55° C. (medium), the time ranges from 25 minutes to 29.8 minutes per pound, averaging 27.9 minutes. In the four roasts cooked to 70° C. (well-done) the time varied from 31.8 minutes to 35.8 minutes, averaging 34.4 minutes per pound.

This rate per pound is considerably greater than the rate necessary to cook the single short rib roasts (not rolled) used in the previous experiments. In the latter case (Table I) only 16.3 minutes per pound were required to cook the meat rare (46.5° C.), 19.2 minutes per pound to cook it medium (60° C.) and 34.4 minutes per pound, very well done (79° C.). This is no doubt due to the difference in shape and size of the two kinds of roasts. In the rolled roasts the meat is in a much more compact form than it is in the short rib roasts. The difference in the number of minutes required per pound in the two kinds of roasts is illustrated in Diagram III and Tables No. I and IV.

RISE OF TEMPERATURE AFTER REMOVAL FROM OVEN

The rise of temperature in the rolled roasts after removal from the oven followed the same rule as in the short rib roasts.

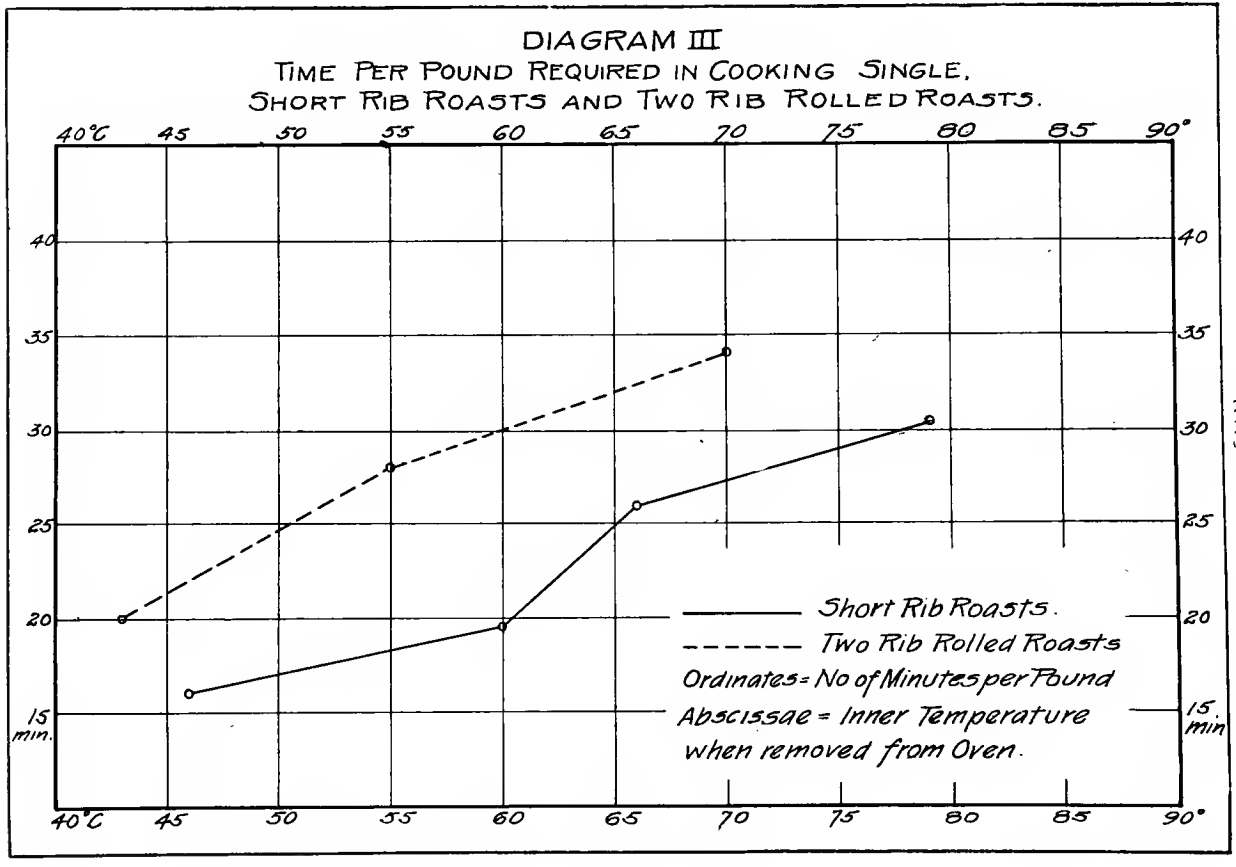


DIAGRAM III
TIME PER POUND REQUIRED IN COOKING SINGLE,
SHORT RIB ROASTS AND TWO RIB ROLLED ROASTS.
40°C 45 50 55 60 65 70 75 80 85 90°
40
35
30
25
20
15 min.
Short Rib Roasts.
Two Rib Rolled Roasts
Ordinates = No of Minutes per Pound
Abscissae = Inner Temperature
when removed from Oven.

TABLE IV. TIME OF COOKING AND INNER TEMPERATURE OF ROASTS AT DIFFERENT OVEN TEMPERATURES.

Number of experiments.	Temperature of oven.	Inner temperature when removed.	Maximum inner temperature.	Rise of inner temperature.			Time of cooking.			Condition of Meat.
				Maximum.	Minimum.	Average.	Maximum.	Minimum.	Average.	
	°C.	°C.	°C.	°C.	°C.	°C.	Mins.	Mins.	Mins.	
Average of 4	195	43	56.1	15	10	13.1	21.1	18.7	20.1	Rare
Average of 2	175	43.8	55.8	12	12	12	18.4	18.1	18.3	Rare
Average of 2	100	56	58	2	2	2	39.7	37.3	38.5	Rare
Average of 8	195	54.9	62.9	10.5	6.5	7.9	29.8	21.8	26.5	Medium rare
Average of 5	175	55.4	63.5	10	7	8.1	30.6	22.9	26.0	Medium rare
Average of 4	100	62.1	63.9	2.5	1.5	1.8	44.3	41.4	42.8	Medium rare
Average of 4	195	70	73.5	4	3	3.5	35.5	31.8	34.4	Well done
Average of 2	175	70	74.3	5	3.5	4.3	33.4	29.3	31.4	Well done
Average of 3	100	72.7	72.7	.....	.....	.....	89.6	69.4	79.8	Well done

That is, the lower the inner temperature of the meat when removed, the greater was the rise after removal. This rise of temperature was however greater in every instance in the rolled, two rib roasts than in the short, single roasts. When removed at 43° C., the average rise in the rolled roasts was 13.1° C., while in the single roasts removed at 46.5° C., it was 7.5° C. At 55° C., the average rise in the rolled roasts was 7.9° C., while at 60° C., in the short rib the rise was 4.5° C. The comparative rise of the inner temperature in the two kinds of roasts is shown in Diagram IV and Tables No. I and IV.

The difference in the rise of temperature in the two cases is seen to be greatest at the lowest temperature. Above 55° C., the rise in the two instances follows almost parallel lines.

INFLUENCE OF TEMPERATURE OF COOKING UPON RISE IN INNER TEMPERATURE AFTER REMOVAL FROM OVEN

The rise of the inner temperature after removal from the

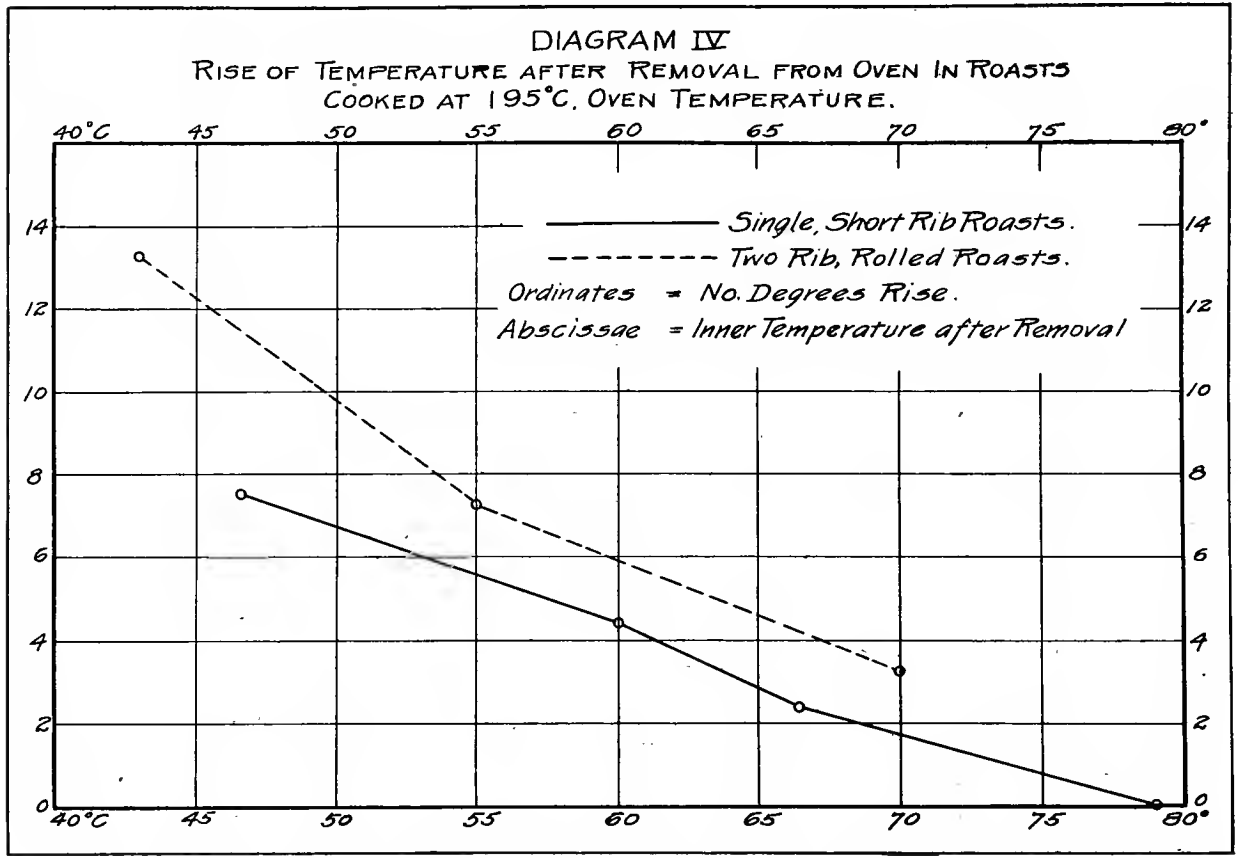


DIAGRAM IV
RISE OF TEMPERATURE AFTER REMOVAL FROM OVEN IN ROASTS
COOKED AT 195°C. OVEN TEMPERATURE.
40°C 45 50 55 60 65 70 75 80°
0 2 4 6 8 10 12 14
Single, Short Rib Roasts.
Two Rib, Rolled Roasts.
Ordinates = No. Degrees Rise.
Abscissae = Inner Temperature after Removal

oven is dependent upon the temperature at which the meat is cooked as well as upon the inner temperature of the meat. In Table IV is shown the maximum, minimum, and average rise of temperature upon removal from the oven, when cooked at the different temperatures. This data is also illustrated in Diagram V.

The average rise in temperature ranges from nothing in the roasts cooked well-done at 100° C. to 13.1° C. in the roasts cooked rare at 195° C. When the roasts were cooked rare at 175° C., the rise of inner temperature is but one degree less than in those equally cooked at 195° C.

In the well-done and medium rare roasts, the rise at the two higher cooking temperatures is very nearly equal. At 100° C. the rise of temperature was the same whether the meat was cooked rare or medium rare. Because of the small rise of temperature observed in the roasts cooked at 100° C., it was found necessary to raise the inner temperature of the meat to a higher degree before removing from the oven so that the maximum temperature after removing from the oven should correspond more nearly with those in the other cases.

The lines showing the rise of the inner temperature in the medium rare and well-done roasts are nearly parallel. The rise of temperature in the rare roasts shows a marked divergence from this parallel.

A similar rise of temperature was noticed by J. Lawrence Hamilton,[1] who says that in large joints there may be a rise of 30° F.

INFLUENCE OF OVEN TEMPERATURE UPON LENGTH OF TIME OF COOKING

When the oven temperature was only 100° C., the number of the minutes per pound required to produce the same degree of cooking was, as was to be expected, considerably greater than the time required at either of the higher temperatures. At 175° C., however, the time of cooking per pound is found to be ac-

[1] Lancet 1894, Dec. 8, p. 1376.

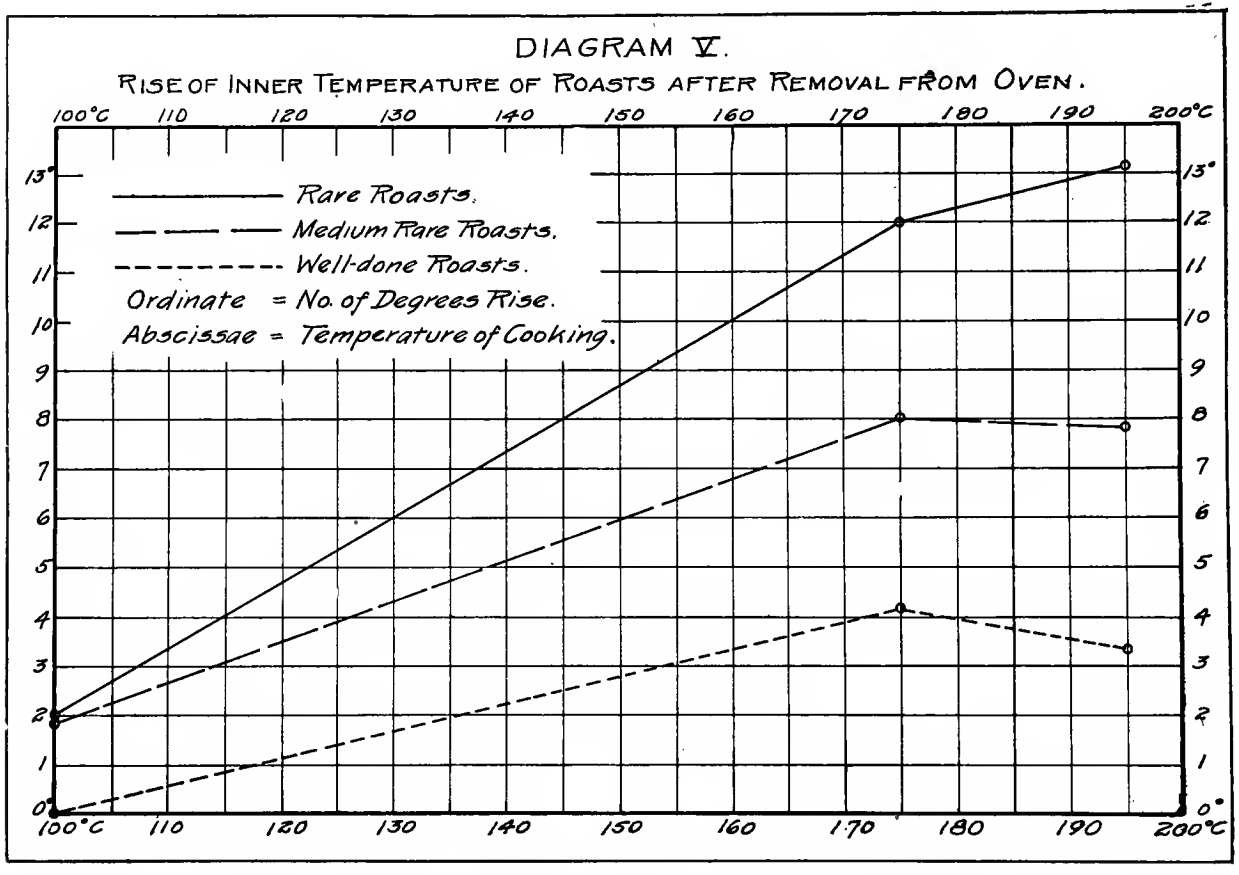


DIAGRAM V.
RISE OF INNER TEMPERATURE OF ROASTS AFTER REMOVAL FROM OVEN.
Rare Roasts.
Medium Rare Roasts.
Well-done Roasts.
Ordinate = No. of Degrees Rise.
Abscissae = Temperature of Cooking.
100°C 110 120 130 140 150 160 170 180 190 200°C
0° 1 2 3 4 5 6 7 8 9 10 11 12 13°

tually less than that at 195° C. In only two cases was the time of cooking per pound at the latter temperature lower than in the corresponding series at 175° C. A comparison of the length of time required to produce the same results is made in Table IV and Diagram VI.

At 100° C., the average time required for the rare roasts was 38.5 minutes per pound, for the medium rare roasts 42.8 minutes, and for the well-done 79.8 minutes per pound. At 195° C., the average time for the rare roasts was 20.1 minutes, for the medium rare 26.5 minutes, and for the well-done 34.4 minutes.

The slightly longer time required at 195° C. than at 175° C. may be due to the fact that at this temperature the outer crust is so hardened and dried that it becomes a poorer conductor of heat. In Diagram VI, it may be seen that the increase in the number of minutes per pound required for the medium and rare roasts at the different oven temperatures follows almost parallel lines. This is true also of the well-done roasts when cooked at 195° C. and 175° C., but from this point to 100° C. the line diverges considerably. Apparently it is much more difficult, at the latter temperature, to raise the temperature of the interior of the meat from 60° C. to 70° C. than it is to raise it from 50° C. to 60° C.

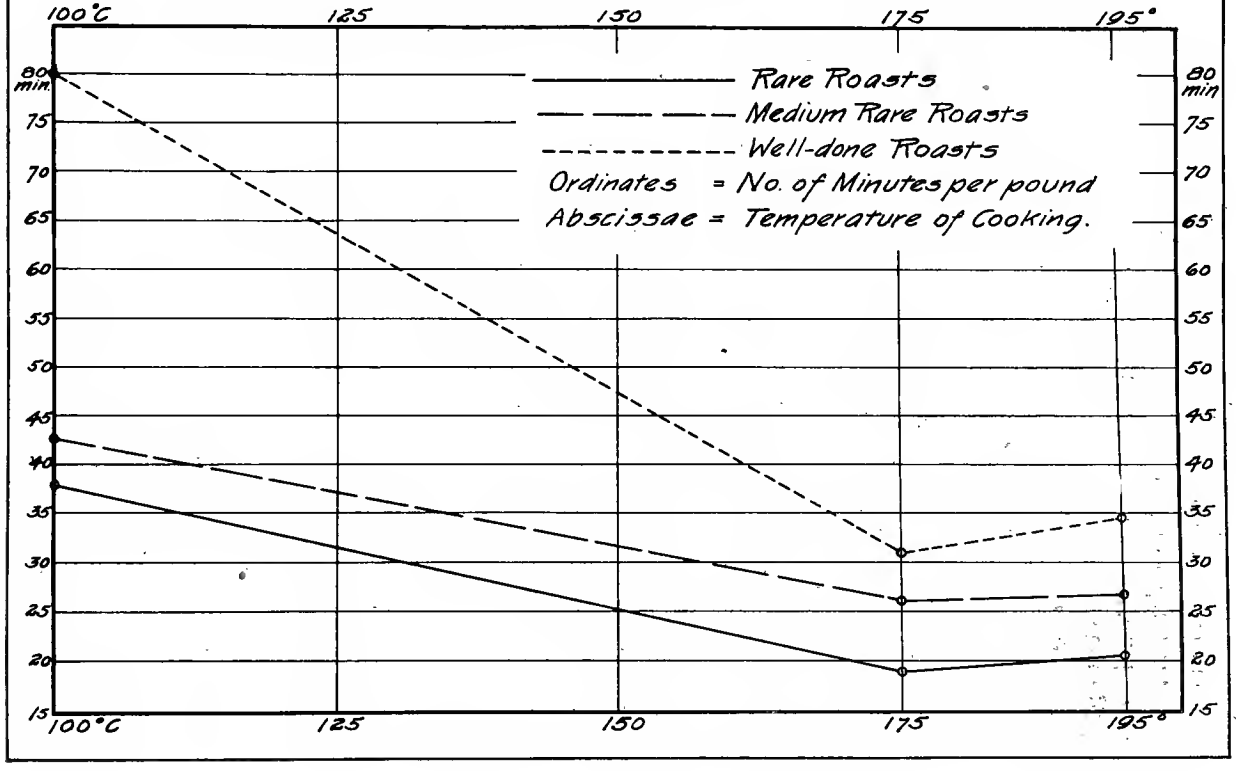
Results of Roasting at Different Temperatures

The physical characteristics of the roasts cooked at different temperatures are also of importance. In general it may be said that the lower the temperature of the oven, the more uniform will be the condition of the interior of the meat. Even in those roasts cooked medium rare in the Aladdin oven at 100° C., the pink coloration extended almost to the surface of the meat.

At all of the temperatures used, the meat was well browned and attractive looking. The temperature of 100° C. in the Aladdin oven proved therefore to be sufficient to retain the

DIAGRAM VI

INFLUENCE OF OVEN TEMPERATURE UPON TIME OF COOKING.



browning produced by the preliminary searing. At 195° C. there was some tendency to over-browning, especially when the roasts were cooked well-done. At the latter temperature also the well-done layer is somewhat deeper than in the meat cooked at 175° C.

In a test made by cooking duplicate samples from the same animal, one in the gas range oven at 195° C. and the other in the Aladdin oven at 100° C., it was agreed that the latter gave the best results in regard to the flavor and juiciness of the meat but that there was little difference in the tenderness of the two roasts. The roast cooked in the gas range seemed more compact and closer in texture and was noticeably drier in the lean part than that cooked in the Aladdin oven.

There is a marked difference in the character of the drippings in the three cases. At 195° C. the color of the melted fat in the drippings ranged from a deep crimson to a topaz yellow. Upon cooling these became lighter in color but were still very much darker than the drippings produced at 175° C. which were almost white. The drippings produced in the Aladdin oven were very scanty in amount, the fat was very light colored, and there was a variable quantity of watery juice.

To produce the most desirable flavor if the drippings are to be used as gravy, a comparatively high temperature is probably necessary. It is desirable however to avoid a temperature sufficiently high to cause excessive decomposition of the fat, which is indicated by the deepening in color, since these decomposition products are irritating and may cause digestive disturbances.

SUPPLEMENTARY EXPERIMENTS

In order to secure further information upon some of the questions raised by the preceding experiments, it was thought desirable to repeat a few of the typical cases in order to observe the temperature in different parts of the rolled roasts. For this purpose the same cuts were used as in the previous experiments, namely, the third and fourth ribs. These were pre-

pared for cooking exactly as before by boning and rolling. Two pairs of the roasts, Nos. 5 and 5a and 7 and 7a were duplicates from the right and left side of the same carcass. The remaining pair, Nos. 6 and 6a, differed considerably in size and weight, and serve best to illustrate the difference in time required, according to the weight of the roasts. The weight, dimensions, and time of cooking of the six roasts are given in Table V. All of these roasts except No. 6 were from heavy and apparently quite mature beef.

TABLE V. Weight, Dimensions, and Time of Cooking Two-rib Rolled Roasts.

Experiment No.	Description of roast.				Temperature of oven.		Time of cooking.			Inner temperature.	
	Weight.		Diameter.	Width across back.	During first 15 minutes	During remainder.	Total time.		Time per pound	When removed.	Maximum after removal.
	Lbs.	Ozs.	Ins.	Ins.	°C.	°C.	Hrs.	Mns.	Mins.	°C.	°C.
5.....	7	4	5¼x7¼	6¼	250	195	2	45	22.7	54	64.5
5a....	7	7	5⅝x8⅜	6¼	250	195	2	43	21.8	55.5	64
6.....	4	7	4½x6¾	5	250	175	2	00	27.	55	64
6a....	7	14	5½x7¾	6¼	250	175	3	00	22.9	57	64.5
7.....	6	0½	5¼x7¼	6¼	250	100	4	10	41.4	62	63.8
7a....	6	6	4¾x6¾	6¼	250	100	4	30	42.2	62	63.5

The experiments were made in duplicate, two roasts being cooked medium rare at each of the three oven temperatures previously used. Three thermometers were inserted in each roast. One was placed as before at the center, a second about a quarter of an inch under the outer surface, and the third half way between these two. The bulbs of the three thermometers were directly in line with each other. The temperature was observed, during the cooking, at fifteen minute intervals and at five minute intervals after removal from the oven, until the maximum temperature was reached.

TEMPERATURE OF THE INTERIOR

The inner temperature observed in each roast is recorded

in Table VI, (page 31) the rise of temperature for each set of duplicates being plotted in Diagrams VII, VIII, and IX. The rise of temperature observed in similar portions of the duplicate roasts is quite uniform in all cases except those cooked at 175° C. The weight and dimensions of these two roasts were quite different and the rise of temperature in the smaller roast was more rapid.

As a result of the preliminary cooking for fifteen minutes at 250° C. there was an immediate and considerable rise of the temperature near the surface. According to Table VI and the accompanying diagrams it may be seen that this initial rise ranged from 34° C. in Roast No. 7 to 13° C. in Roast No. 6a. In the latter instance the thermometer was however more deeply imbedded in the meat than in the other cases.

The temperature at the center of the meat was very little affected by this first heating but after this period the temperature of the interior rose at a more rapid rate than did that of the exterior. The rate of rise at the intermediate point was about the same as that at the center.

The difference in the uniformity with which the roasts are cooked under these various conditions is shown by the variations in the temperature at the three points. In the roasts cooked at 195° C. the difference in temperature between the center and intermediate point when removed from the oven averaged 9° C. Between the center and the surface the average difference in temperature was 25° C. The differences in temperature in the roasts cooked at 175° C. were, between the center and intermediate point 5° C., between the center and the surface 13° C. In the roasts cooked at 100° C. the variation in the temperature between the center and the intermediate point was 1° C. and between the center and the surface 5° C. It is evident that since in the roasts cooked at the lower temperature the degrees of heat reached in the different portions are very similar, the meat will be found in very nearly the same condition throughout.

It is interesting to note that a slight difference in the tem-

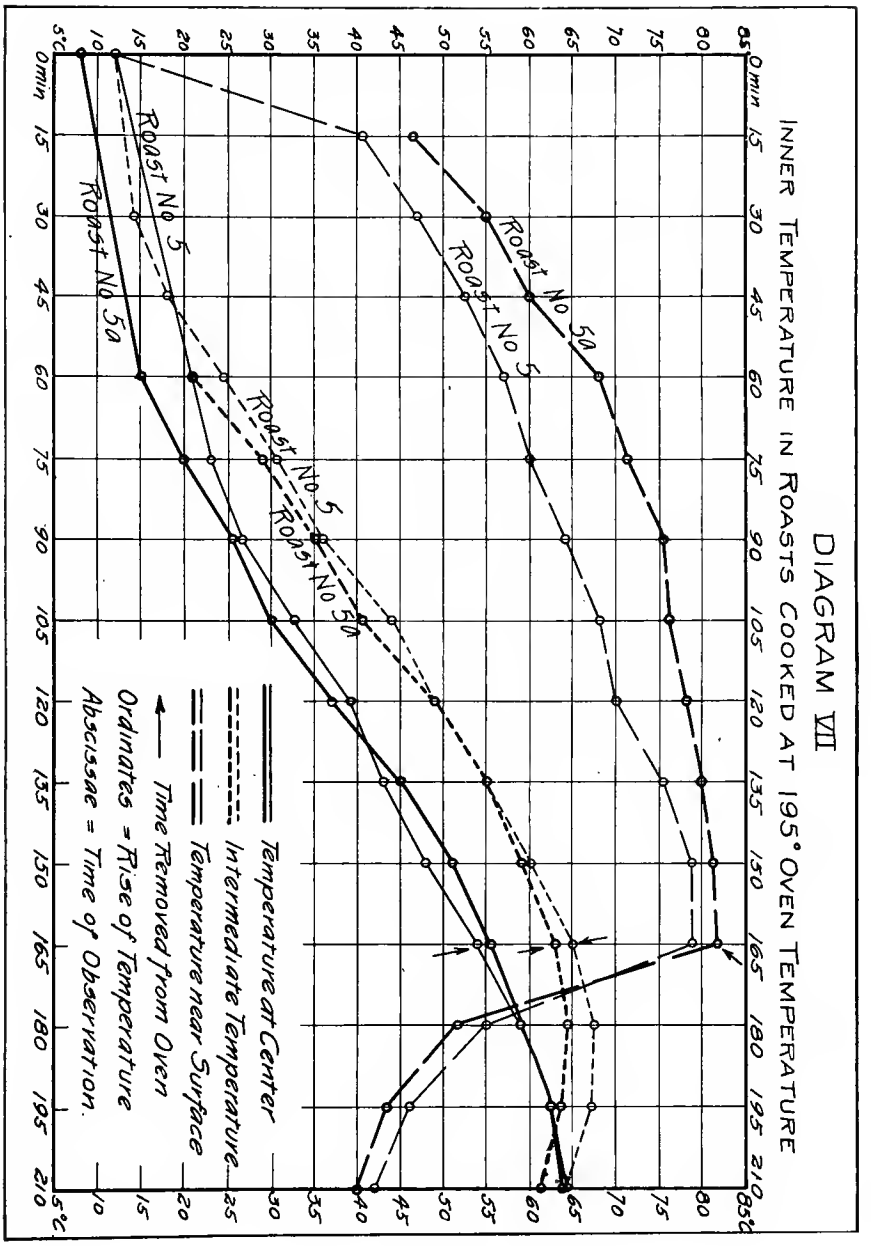


DIAGRAM VII
INNER TEMPERATURE IN ROASTS COOKED AT 195° OVEN TEMPERATURE
ROAST NO 5A
ROAST NO 5
ROAST NO 5
ROAST NO 5A
ROAST NO 5
ROAST NO 5A
Temperature at Center
Intermediate Temperature
Temperature near Surface
Time Removed from Oven
Ordinates = Rise of Temperature
Abscissae = Time of Observation.

[313]

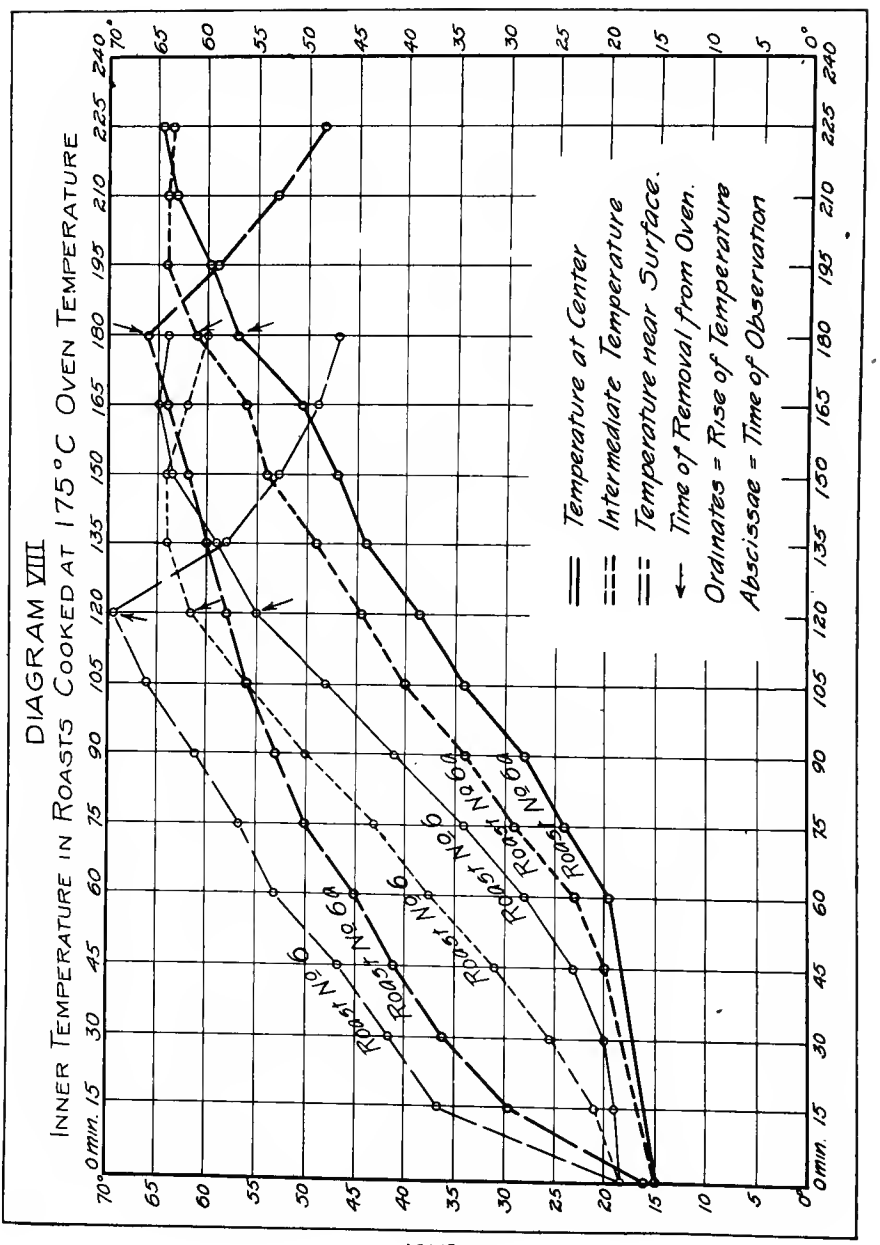


DIAGRAM VIII
INNER TEMPERATURE IN ROASTS COOKED AT 175°C OVEN TEMPERATURE
Temperature at Center
Intermediate Temperature
Temperature near Surface.
Time of Removal from Oven.
Ordinates = Rise of Temperature
Abscissae = Time of Observation
Roast No 6
Roast No 6
Roast No 6
Roast No 6
Roast No 6
Roast No 6
0 min. 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240
70° 65 60 55 50 45 40 35 30 25 20 15 10 5 0°

[314]

TABLE VI. INNER TEMPERATURE IN TWO-RIB ROLLED ROASTS.

Length of time.		Cooked at 195° C oven temperature.						Cooked at 175° C. oven temperature.						Cooked at 100° C. oven temperature.					
		Temperature at center.		Temperature of the intermediate flesh.		Temperature near surface.		Temperature at center		Temperature of the intermediate flesh.		Temperature near surface.		Temperature at center.		Temperature of the intermediate flesh.		Temperature near surface.	
		Experiment 5.	Experiment 5a.	Experiment. 5.	Experiment 5a.	Experiment 5.	Experiment 5a.	Experiment 6.	Experiment 6a.	Experiment 6.	Experiment 6a.	Experiment 6.	Experiment 6a.	Experiment 7.	Experiment 7a.	Experiment 7.	Experiment 7a.	Experiment 7.	Experiment 7a.
Hrs.	Mins. (a) In oven.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.	° C.
.....	.....	11.5	8	11.5	.....	12	.....	18.5	15	18.5	15	18.5	16	18	12	18	12	18	16
	15	.....	.....	.....	.....	40.5	46.5	19	.....	21	.....	36.5	29.5	.....	.....	20	.....	52	47
	30	.....	.....	14.5	.....	47	55	20	.....	25.5	.....	41.5	36.1	20	14	22.5	15	53.5	54
	45	.....	.....	18	.....	52.5	60	23	.....	31	20	46.5	41	22	16.2	27	19	55	52
1	00	.....	15	24.5	21	57	68	28	19.5	37.5	23	53.1	45	25.5	20	31	24.5	53	54
1	15	23	20	30.5	29	60	71.5	34	24	43	29	56.5	50	29.5	24	35	28.5	51	55
1	30	26	25.5	36	35	64	75.5	41	28	50	34	61	53	33	28.5	38	33.5	56	57
1	45	32	30	44	40.5	68	76	48	34	56	40	66	56	37	32	40	37	58.5	58
2	00	37	39	49	49	70	78	55	38.5	61.5	44.5	69.5	58	40.5	36.8	44.5	41.5	59.5	60.5
2	15	43	45	55	55	75.5	80	.....	44	.....	49	.....	60	44.5	40	47.5	44	62.5	62
2	30	48	51	60	59	79	81	.....	47	.....	54	.....	62	47.5	44	50	47.5	63	64
2	45	54	55.5	65	63	79	81.5	.....	50.5	.....	56	.....	64	50	47	52.7	50	65	65
3	00	.....	.....	.....	.....	.....	.....	.....	57	.....	61	.....	66	53	50	55.5	52.5	66.5	64
3	15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	55	52.5	57	55	64.5	65
3	30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	57	55	59	57	66	65
3	45	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	59.5	57	60	59	68	67
4	00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	61.5	59	62	60	67.7	67
4	15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	62	61	62.5	62	65	69
4	30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	62	.....	63	.....	69
(b) After removal.																			
	5	55.5	56	65.5	63.5	68	64	56	57.5	62.5	61	62.5	64	62	62	62.8	63	52.8	59
	10	56.5	57.5	66.5	64.5	59	57	58	58.5	63	63	60	62	62.8	62.5	62.8	63.7	48	53.5
	15	59	59	67.5	64.5	53	51.5	59	59.8	64	64	58	59	63.3	63	62.8	64	44.5	51.5
	20	60	60.5	67.5	64.5	50	47	61	61	64	64.5	55.5	55.5	63.8	63	62.2	64	.....	47
	25	61.5	61.7	67.5	64	47.5	44.5	62.5	62	64	64.5	54	55	63.8	63.5	62	64	.....	46
	30	62.5	62.4	67	63.7	46	43.2	63.5	63	64	64.5	52.8	53	....	63.5	.....	64	.....	45
	35	63.5	63	66	63	43.5	41.5	64	64	63.5	64	51.5	51	.....	63.5	.....	63.2	.....	43.5
	40	64	63.5	65	62	42.5	40.5	64	64	63	63.8	50	50	.....	63	.....	62.5	.....	42.5
	45	64.5	64	64.5	61.5	42	39.8	65	64.5	62	63.5	49	48.5	.....	.....	.....	.....	.....	.....
	50	64.5	64	63	60.5	41	39	65	64.5	61 +	62.5	48	47.5	.....	.....	.....	.....	.....	.....
	55	.....	64	.....	59.5	.....	38	64	.....	61	.....	48	.....	.....	.....	.....	.....	.....	.....
	60	.....	63.5	.....	58.8	.....	37.5	64	.....	60 +	.....	47	.....	.....	.....	.....	.....	.....	.....

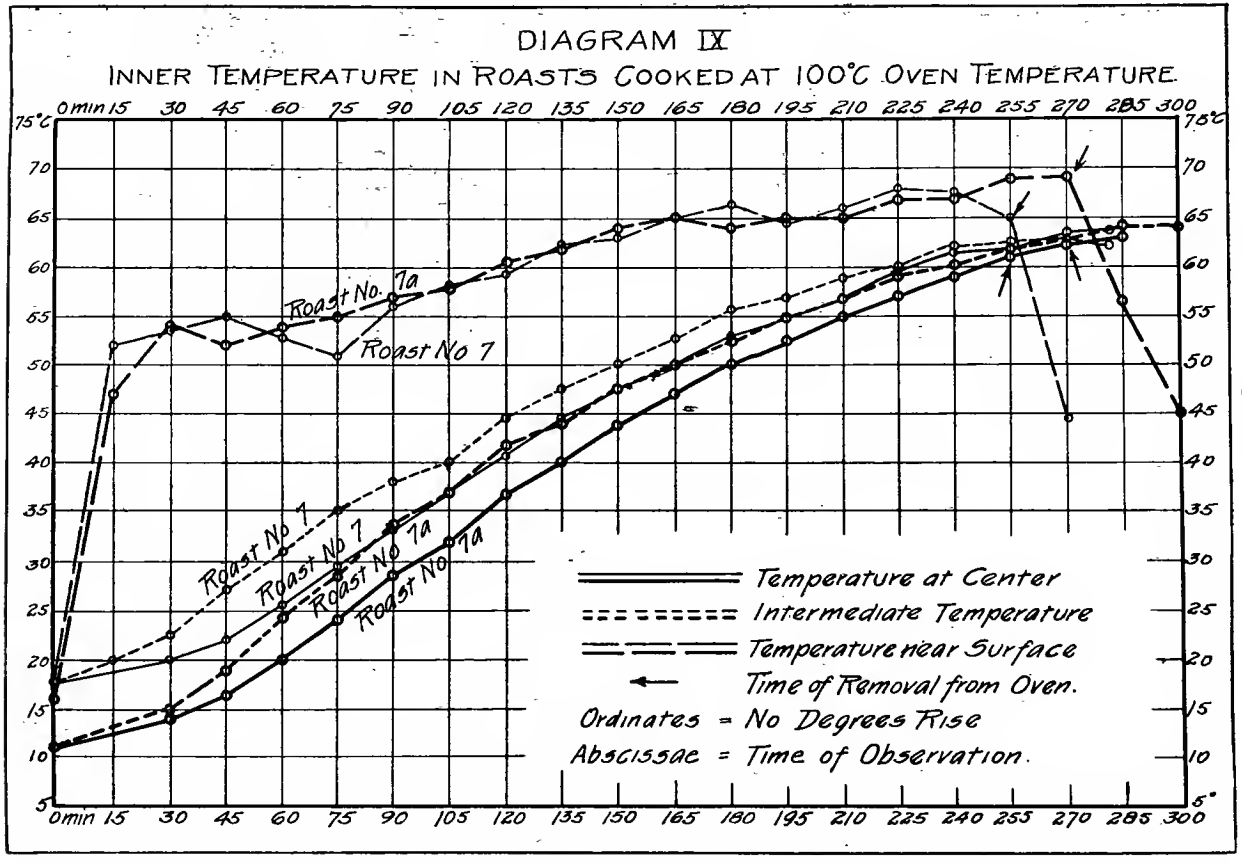


DIAGRAM IX
INNER TEMPERATURE IN ROASTS COOKED AT 100°C OVEN TEMPERATURE.
0 min 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300
75°C 70 65 60 55 50 45 40 35 30 25 20 15 10 5°
Roast No. 7a
Roast No 7
Roast No 7
Roast No 7
Roast No 7a
Roast No 7a
Temperature at Center
Intermediate Temperature
Temperature near Surface
Time of Removal from Oven.
Ordinates = No Degrees Rise
Abscissae = Time of Observation.

perature of the roasts before going into the oven does not exert a marked difference upon the subsequent rise of temperature. For example, there was a difference of 6° C. between the temperature of the centers of Nos. 7 and 7a before these were placed in the oven, but this difference gradually diminished until it was reduced to but 1° C. fifteen minutes before the latter was removed from the oven. The same fact is shown in the roasts cooked at 195° C. Here there was a difference of but 3° C., in the initial temperature but that which had the lower temperature at the beginning rose above the other during cooking.

A comparison of the averages of the temperature at the centers of the duplicate roasts (See Diagram X) shows that at 100° C. the temperature during the first hour of cooking rose the most rapidly. After the first hour the rise was most rapid in the roasts cooked at 195° C. During the whole time the rise of temperature at 175° C. occupies an intermediate position.

The same diagram illustrates the difference in the rate of rise of the temperature of the single short rib and the rolled rib roasts. The average weight of the former was $3\frac{3}{4}$ pounds and of the latter 7 pounds. The time required to attain a temperature of 55° C. at the center of each was one hour for the former and two and three-fourths hours for the latter. Hence it is evident that the size and shape of the roast has a marked influence upon the time required. The greater amount of surface exposed by the single short rib roast in proportion to its cubic contents makes it possible for the heat to penetrate to its center at a much more rapid rate than in the rolled roasts.

The difference in the time required to cook two roasts of the same character but of different weights is illustrated by Nos. 6 and 6a. The former weighing 4 lbs. 7 ozs. required at the rate of 27 minutes per pound and the latter weighing 7 lbs. 14 ozs. but 22.9 minutes per pound to reach the same degree. It may be said in general that other things being equal the heavier the roast, the less will be the time per pound required to cook it.

After the roast is removed from the oven the temperature

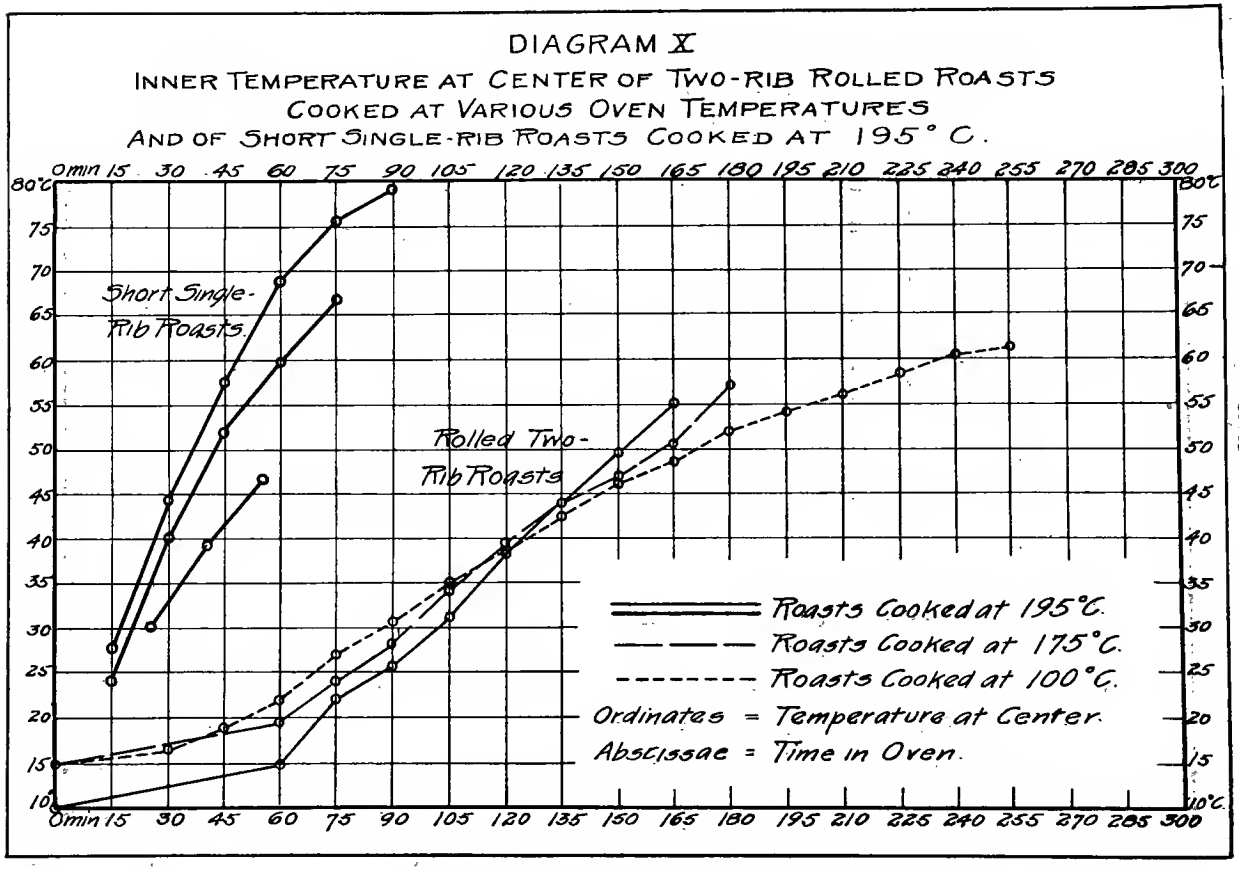


DIAGRAM X
INNER TEMPERATURE AT CENTER OF TWO-RIB ROLLED ROASTS
COOKED AT VARIOUS OVEN TEMPERATURES
AND OF SHORT SINGLE-RIB ROASTS COOKED AT 195° C.
0min 15 30 45 60 75 90 105 120 135 150 165 180 195 210 225 240 255 270 285 300
80°C 75 70 65 60 55 50 45 40 35 30 25 20 15 10°C
Short Single-Rib Roasts.
Rolled Two-Rib Roasts
Roasts Cooked at 195°C.
Roasts Cooked at 175°C.
Roasts Cooked at 100°C.
Ordinates = Temperature at Center.
Abscissae = Time in Oven.

of the exterior drops immediately, the most rapid fall occurring during the first fifteen minutes, after which it is more gradual. The temperature of the center rises slowly and steadily during a period of from 30 minutes in the roasts cooked at 100° C., to 45 minutes in those cooked at 175° C., or 195° C. As before stated the rise is greatest when the cooking has been carried on at the latter temperatures. The temperature at the intermediate point rises slowly for from 15 to 30 minutes after removal from the oven and then falls very slowly.

In this supplementary set of experiments the only roast (No. 6a) cooked at 175° C. which can be compared with those cooked at 195° C. required about the same time per pound, the rise of temperature being a little more gradual.

CONCLUSIONS

As a result of the foregoing observations it may be concluded:

1. That the conditions of the interior of a roast may be quite accurately determined and therefore the degree of cooking controlled by observing the temperature reached in the center of the meat.

2. That, except in the case of the roasts cooked well-done at 100° C., there is always a rise of temperature in the center of the meat after being removed from the oven, when cooked under the conditions of these experiments, if the meat is not cut.

3. That this rise of temperature depends upon (1) the temperature of cooking and (2) the temperature of the interior of the roast when removed from the oven, (3) the size and shape of the roast.

4. That the number of minutes per pound necessary to produce a certain degree of cooking depends upon (1) the character of the cut as regards size, shape, etc., and (2) the temperature of the oven. For example, a single short rib roast containing the bone required 16.3 minutes per pound to cook the meat rare, while the two-rib rolled roasts averaged 20.1 minutes at the same temperature to reach the same condition.

5. That the roasts are as quickly cooked at 175° C.; as at 195° C. This is important from a practical stand point as it involves a question of economy in fuel, especially if gas is the fuel used.

6. When cooked at 100° C., a very much longer time is required to raise the inner temperature from medium (62° C.) to well-done (72° C.) than to cause the same rise at 195° C. or 175° C. There is therefore very much less danger of over-cooking the meat at this temperature (100° C.). At the higher temperature a very few minutes over-cooking may be sufficient to carry the inner temperature above the desired degree.

7. That the lower the temperature of cooking, the more uniform is the condition of the interior of the meat.

8. That by any of the methods of cooking used in these experiments an attractive appearance is produced.

PLATE I.— SHORT RIB BEEF ROAST — VERY RARE

PLATE II.—SHORT RIB BEEF ROAST—MEDIUM RARE

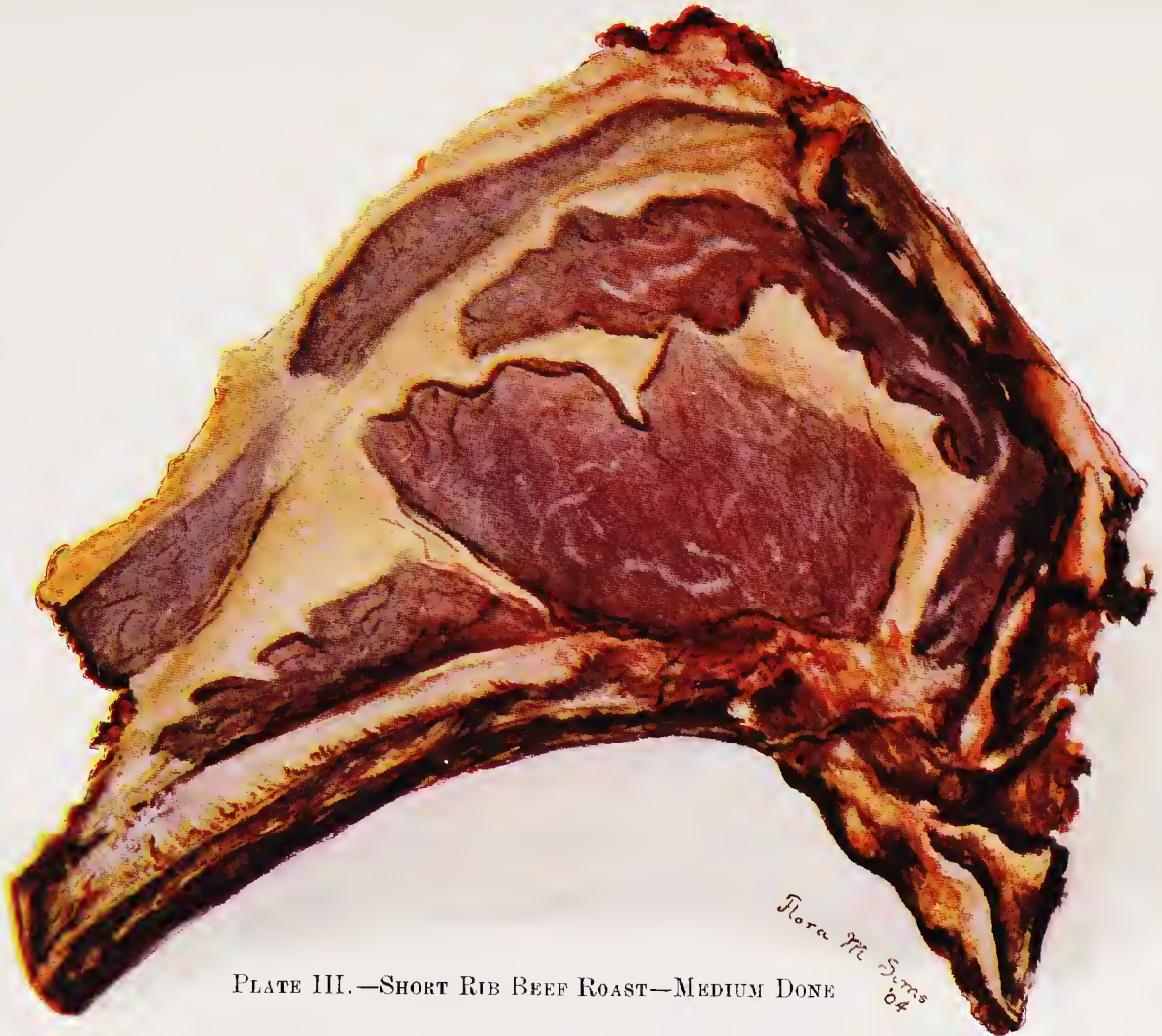


PLATE III.—SHORT RIB BEEF ROAST—MEDIUM DONE

PLATE IV.—SHORT RIB BEEF ROAST—WELL DONE

NUMBERS OF THE UNIVERSITY STUDIES PREVIOUSLY ISSUED

VOL. I.

[Address all communications concerning the Studies to Editor, University Studies, 305 University Hall, Urbana, Ill.]

No. 1. Abraham Lincoln: The Evolution of his Literary Style. By D. K. Dodge, Ph.D. 25 cts.

No. 2. The Decline of the Commerce of the Port of New York. By Richard Price Morgan, Dr. Eng'g. *Out of print.*

No. 3. A Statistical Study of Illinois High Schools. By F. G. Bonser, M.S. 25 cts.

No. 4. The Genesis of the Grand Remonstrance from Parliament to King Charles I. By Henry Lawrence Schoolcraft, Ph.D. 25 cts.

No. 5. The Artificial Method for Determining the Ease and the Rapidity of the Digestion of Meats. By Harry Sands Grindley, Sc.D. and Timothy Mojonnier, M.S. 25 cts.

No. 6. Illinois Railway Legislation and Commission Control since 1870. By Joseph Hinckley Gordon, A.M. Introduction by M. B. Hammond, Ph. D. 25 cts.

No. 7. The Coals of Illinois; Their Composition and Analysis. By S. W. Parr, M.S. *Out of print.*

No. 8. The Granger Movement in Illinois. By A. E. Paine, A.M. 35 cts.

No. 9. The Illinois Constitutional Convention of 1862. By O. M. Dickerson, Ph.D. 35 cts.

No. 10. Labor Organizations Among Women. By Belva M. Herron, B.L. One Dollar.

VOL. II.

No. 1. Illinois Libraries. Part 1. By Katharine L. Sharp, M.L.S. One Dollar.

No. 2. Epithelial Degeneration, Regeneration, and Secretion in the Mid-Intestine of Collembola. By J. W. Folsom, Sc.D., and Miriam U. Welles, A.M. One Dollar.

No. 3. Illinois Libraries. Part 2. By Katharine L. Sharp, M.L.S. One Dollar.